GEOLOGIC INVESTIGATIONS SERIES I-2634

exemplified in the southern Bridger Range (Miller and Lageson, 1993; cross section C-C')

rocks generally fall in the range of 3.2-2.7 Ga. (James and Hedge, 1980; Mueller and others, 1985; Mogk and Henry, 1988; Wooden and others, 1988; Mogk and others, 1992), although zircons have been dated as old as 3.96 Ga from quartzites in the Beartooth Mountains (Mueller and others, 1992). The metamorphic fabric of these basement rocks has in some cases exerted a strong control on the geometry of subsequent Proterozoic and Phanerozoic structures, particularly Laramide folds (Miller and Lageson, 1993). The important variable is the attitude of basement foliation with respect to the basement-cover nonconformity; where foliation is subparallel to the nonconformity and overlying stratigraphy, then the basement is folded concordantly with cover rocks; where foliation is sub-perpendicular to the nonconformity, then passive-slip mechanisms of basement deformation prevail in the cores of Laramide folds as Middle Proterozoic rocks in the central Bridger Range correlate with lower units of the Belt Supergroup to the northwest (Winston, 1986a) and are known to be older than 1.449 Ma and younger than 1.468 Ma (Aleinikoff and others, 1996). McMannis (1963) was the first to understand that the juxtaposition of Middle Proterozoic conglomerates containing Archean clasts and Archean rocks along the Pass fault marks the vicinity of the southern margin of the Belt basin. As early as 1894, however, Iddings and Weed (Iddings and Weed, 1894) had mapped the general distribution of

D₁: Sevier Folding and Thrusting The youngest synorogenic rocks in the Sedan area, the Nixon Peak Conglomerate Lens of the Late Cretaceous to Middle Paleocene Fort Union Formation (Roberts, 1972), were already in place before local Sevier fold-thrust deformation began, probably in late Paleocene time (Skipp and McGrew, 1968; Harlan and others, 1988). An Eocene(?) mafic dike intrudes the updip termination of the rotated Pass thrust fault (McMannis, 1955; this paper). Paleomagnetic and isotopic dating of alkalic dikes and sills of compositions similar to this dike in the Crazy Mountains Basin about 50 km to the northeast yielded post-deformational dates of 52-48 Ma, early middle Eocene (Harlan and others, 1988). Thus, fold-thrust deformation in the Sedan area is bracketed as post-Middle Paleocene and pre-Middle Eocene. The Cross Range and Pass thrust faults were active at this time, as was initial back-thrusting along the Battle Ridge shear zone. Laramide uplift of the ancestral Bridger Range closely followed fold-thrust deformation.

A second phase of contractional deformation involved uplift of the ancestral Bridger Range anticlinorium, a basement-cored Laramide-style uplift (McMannis, 1955; Skipp and McGrew, 1968; Lageson, 1989). There is approximately 7,600 m of structural relief on the Archean basement at the south end of the Bridger Range. No major thrust faults crop out along the eastern flank of the Bridger Range to account for this relief. However, Sohio Oil Company seismic and drilling data (Lageson, 1989) confirmed the existence of a west-dipping zone of thrust faults (sub-Bridger thrust zone of Lageson, 1989) that bounds the east flank of the Bridger Range, producing a Laramide-style "basement-overhang." As the sub-Bridger thrust zone translated up-section into the Livingston Group, it delaminated the Sedan Formation from superjacent strata to produce the Battle Ridge-Bangtail back-thrust and folded the Fort Union and Hoppers Formations in the process. As the ancestral Bridger Range uplift rose, the Pass and Cross Range fault zones were rotated into their present orientations and severe crowding developed between the sub-Bridger thrust zone and the southwest end of Battle Ridge, producing a detachment fault in the lower sandstone member of the Sedan Formation (the Ksl detachment) and disharmonic box folds north of Battle Ridge. The timing of Laramide uplift is bracketed by the following: (1) The youngest rock deformed by uplift of the ancestral Bridger Range is the Late Cretaceous to Middle Paleocene Fort Union Formation (Roberts, 1972); (2) directly south of the Bridger Range, the Absaroka-Gallatin volcanic field blankets Laramide structures in the Gallatin Range with pronounced angular unconformity. Volcanism began around 53 Ma and continued to about 43 Ma, clearly postdating Laramide deformation (Chadwick, 1972). Thus, Laramide uplif in the area is also bracketed as late Paleocene to Eocene. Structural relationships show, however, that Laramide uplift deformed Sevier folds and thrusts, so that within the late Paleocene to Eocene time period, late Paleocene Sevier deformation was closely followed by probable early Eocene Laramide thrusting and uplift of the Bridger Range. Late-

McMannis (1955) mapped a range-front normal fault at the break in slope along the western base of the Bridger Range. This fault is shown south of Ross Pass on the Sedan quadrangle, but it extends the full length of the range beyond the western edge of the map area. The range-front normal fault has down-dropped the Gallatin River valley along its segmented trace, but overall it appears that the valley collapsed along the axial surface of the ancestral Bridger Range anticlinal uplift, leaving the east-dipping limb as a "perched basement wedge" (Lageson, 1989). Regionally, the range-front normal fault is parallel to Winston's (1986b) "Townsend line," suggesting reactivation of a deeper, Middle Proterozoic zone of weakness. Tertiary sedimentary rocks within the eastern Gallatin River valley dip 2°–35° E. toward the normal fault, suggesting that the Gallatin River valley block has rotated clockwise (looking northward) during deformation. On the basis of preliminary gravity modeling, Lageson (1989) reported that the Gallatin River valley is an asymmetric half-graben having a maximum sediment thickness of about 2 km, with 2,200 m of throw on the adjacent range-front fault. The gravity model casts strong doubt on the existence of pre-Tertiary Phanerozoic rocks of any The onset of post-Laramide crustal extension in southwestern Montana has historically been based on the textural differences of the Eocene-Oligocene Renova and Miocene Sixmile Creek Formations, constituting the "Bozeman Group" (Kuenzi and Fields, 1971; Fields and others, 1985). These two units are separated by the "mid-Tertiary unconformity," widely recognized throughout the region. The change from predominantly fine-grained fluvial and lacustrine sediments (Renova) to predominantly coarse-grained volcaniclastic sandstone and conglomerate (Sixmile Creek) is often cited as heralding the onset of modern Basin and Range extension in the Three Forks Basin (Lageson, 1989). However, mpson and others (1982) called upon four major changes in climate during the Tertiary to account for the differences in sediment texture. Hanneman and Wideman (1991) used calcic paleosol zones to delimit five sequence stratigraphic units within the Bozeman Group and correlated sequence 4 (Sixmile Creek) with "partially filled extensional basins." In the Paradise Valley, Burbank and Barnosky (1990) reported that extension began at 17 Ma, immediately following the mid-Tertiary unconformity. However, the presence of gently tilted Eocene through Miocene sedimentary rocks on the surface in the Three Forks and other basins in southwestern Montana, coupled with prograding alluvial fans, entrenched

REFERENCES CITED

Aleinikoff, J. M., Evans, K.V., Fanning, C.M., Obradovich, J.D., Ruppel, E.T., Zieg, J.A., and Steinmetz, J.C., 1996, SHRIMP U-Pb ages of felsic igneous rocks, Belt Supergroup, western Montana: Geological Society of America Abstracts with Programs, 1996 Annual Meeting, p. A–376. Anders, A.M., Geissman, J.W., Piety, L.A., and Sullivan, J.T., 1989, Parabolic distribution of circum-eastern Snake River Plain seismicity and latest Quaternary faulting-Migratory pattern and association with the Yellowstone hot spot: Journal of Geophysical Research, v. 94, p. 1589–1621 Boyer, S.E., 1986, Styles of folding within thrust sheets—Examples from the Appalachians and Rocky Mountains of the U.S.A. and Canada: Journal of Structural Geology, v. 8, p. 325-339. Burbank, D.W., and Barnosky, A.D., 1990, The magnetochronology of Barstovian mammals in southwestern Montana and implications for the initiation of Neogene crustal extension in the northern Rocky Mountains: Geological Society of America Bulletin, v. 102, p. 1093–1104. Chadwick, R.A., 1972, Volcanism in Montana: Northwest Geology, v. 1, p. 1–20. Craiglow, C.J., 1986, Tectonic significance of the Pass fault, central Bridger Range, Montana: Bozeman, Montana State Fenneman, N.M., 1946, Physical divisions of the United States: Washington, D.C., U.S. Geological Survey map, scale Fields, R.W., Rasmussen, D.L., Tabrum, A.R., and Nichols, R., 1985, Cenozoic rocks of the intermontane basins of western Montana and eastern Idaho—A summary, in Flores, R.M., and Kaplan, S.S., eds., Cenozoic Mineralogists, Rocky Mountain Section, p. 9–36.

paleogeography of the west-central United States: Denver, Colo., Society of Economic Paleontologists and Fryxell, J.C., and Smith, D.L., 1986, Paleotectonic implications of arkose beds in Park Shale (Middle Cambrian), Bridger Range, south-central Montana, in Peterson, J.A., ed., Paleotectonics and sedimentation in the Rocky Mountain region, United States: American Association of Petroleum Geologists Memoir 41, pt. II, p. 159–172. Garrett, H.L., 1972, Structural geology of the Crazy Mountains Basin, in Lynn, John, Balster, C., and Warne, J., eds., Crazy Mountains Basin: Montana Geological Society Guidebook, 21st Annual Field Conference, 1972, p. Hackett, O.M., Visher, F.N., McMurtrey, R.G., and Steinhilber, W.L., 1960, Geology and ground-water resources of the Gallatin Valley, Gallatin County, Montana: U.S. Geological Survey Water-Supply Paper 1842, 282 p. Hanneman, D.L., and Wideman, C.J., 1991, Sequence stratigraphy of Cenozoic continental rocks, southwestern Montana: Geological Society of America Bulletin, v. 103, p. 1335–1345. Harlan, S.S., Geissman, J.W., Lageson, D.R., and Snee, L.W., 1988, Paleomagnetic and isotopic dating of thrust-belt deformation along the eastern edge of the Helena salient, northern Crazy Mountains Basin, Montana: Geological Society of America Bulletin, v. 100, p. 492–499. Harrison, J.E., Griggs, A.B., and Wells, J.D., 1974, Tectonic features of the Precambrian Belt Basin and their influence on post-Belt structures: U.S. Geological Survey Professional Paper 866, 15 p. Hunter, R.B., 1987, Timing and structural relations between the Gros Ventre foreland uplift, the Prospect thrust system, and the Granite Creek thrust, Hoback Basin, Wyoming, in Miller, W.R., ed., The thrust belt revisited: Wyoming Geological Association Guidebook, 38th Field Conference, 1987, p. 109–131. Iddings, J.P., and Weed, W.H., 1894, Geologic atlas of the United States, Livingston Folio, Montana: U.S. Geological James, H.L., and Hedge, C.E., 1980, Age of the basement rocks of southwest Montana: Geological Society of America Kellogg, K.S., Schmidt, C.J., and Young, S.W., 1995, Basement and cover-rock deformation during Laramide contraction in the northern Madison Range (Montana) and its influence on Cenozoic Basin Formation: American Association of Petroleum Geologists Bulletin, v. 79, no. 8, p. 1117–1137. Kuenzi, W.D., and Fields, R.W., 1971, Tertiary stratigraphy, structure and geologic history, Jefferson Basin, Montana: Geological Society of America Bulletin, v. 82, p. 3373–3394. Lageson, D.R., 1989, Reactivation of a Proterozoic continental margin, Bridger Range, southwestern Montana, in French, D.E., and Grabb, R.F., eds., Geologic resources of Montana: Montana Geological Society Field Conference Guidebook—Montana Centennial Edition, v. I. p. 279–298. Locke, W.W., and Lageson, D.R., 1989, Geology and geomorphology of the Rocky Mountains/Great Plains transition, in French, D.E., and Grabb, R.F., eds., Geologic resources of Montana: Montana Geological Society Field Conference Guidebook—Montana Centennial Edition, v. II. p. 462–476. Marvin, R.F., Mehnert, H.H., Naeser, C.W., and Zartman, R.E., 1989, U.S. Geological Survey radiometric ages—Compilation "C," Part five—Colorado, Montana, Utah, and Wyoming: Isochron West, no. 53, p. 14–19. McMannis, W.J., 1955, Geology of the Bridger Range, Montana: Geological Society of America Bulletin, v. 66, p. -----1963, LaHood Formation—A coarse facies of the Belt Series in southwestern Montana: Geological Society of ---1965, Resume of depositional and structural history of western Montana: American Association of Petroleum

Miller, E.W., and Lageson, D.R., 1993, Influence of basement foliation attitude on geometry of Laramide basement deformation, southern Bridger Range and northern Gallatin Range, Montana, in Schmidt, C.J., Chase, R.B., and Erslev, E.A., eds., Laramide basement deformation in the Rocky Mountain foreland of the Western United States: Geological Society of America Special Paper 280, p. 73–88. Mogk, D.M., and Henry, D.J., 1988, Metamorphic petrology of the northern Archean Wyoming province, southwestern Montana—Evidence for Archean collisional tectonics, in Ernst, W.G., ed., Metamorphism and crustal evolution of the Western United States [Rubey Volume VII]: Englewood Cliffs, N.J., Prentice Hall, Inc., p. 362–381. Mogk, D.M., Mueller, P.A., and Wooden, J.L., 1992, The nature of Archean boundaries—An example from the northern Wyoming Province: Precambrian Research, v. 55, p. 155–168. Mueller, P.A., Wooden, J.L., Henry, D.J., and Bowes, D.R., 1985, Archean crustal evolution of the eastern Beartooth Mountains, Montana and Wyoming, in Czamanske, G.K., and Zientek, M.L., eds., The Stillwater Complex, Montana—Geology and guide: Montana Bureau of Mines and Geology Special Publication 92, p. 9–20.

Battle Ridge and the Bangtails Mueller, P.A., Wooden, J.L., and Nutman, A.P., 1992, 3.96 Ga zircons from an Archean quartzite, Beartooth Mountains, Montana: Geological Society of America Bulletin, v. 20, p. 327–330. O'Neill, J.M., Schmidt, C.J., Ferris, D.C., and Hanneman, D.L., 1986, Recurrent movement along northwest-trending

Pierce, K.L., and Morgan, L.A., 1992, The track of the Yellowstone hot spot—Volcanism, faulting, and uplift, in Link, P.K., Kuntz, M.A., and Platt, L.B., eds., Regional geology of eastern Idaho and western Wyoming: Geological Society of America Memoir 179, p. 1–53. Piombino, Joseph, 1979, Depositional environments and petrology of the Fort Union Formation near Livingston, Montana—An evaluation as a host for sandstone type uranium mineralization: Missoula, University of Montana, Price, R.A., and Fermor, P.R., 1984, Structure section of the Cordilleran foreland thrust and fold belt west of Calgary, Alberta: Geological Survey of Canada Paper 84–14, scale 1:250,000. Raisz, Erwin, 1957, Landforms of the United States: Melrose, Mass., Raisz Landform Maps, Sixth Revised Edition. Roberts, A.E., 1963, The Livingston Group of south-central Montana, in Short papers in geology and hydrology: U.S.

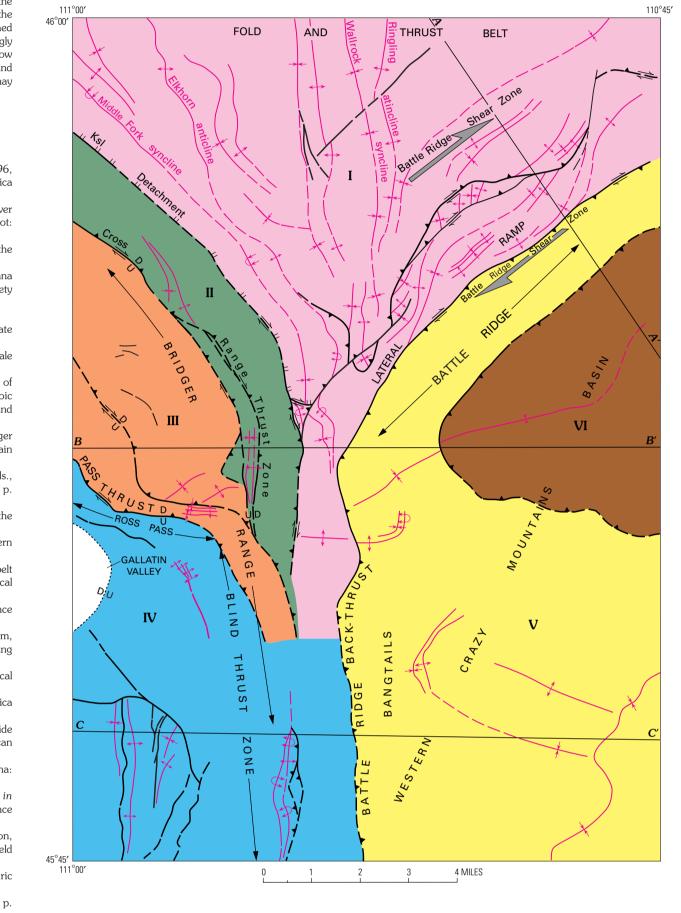
Geological Survey Professional Paper 475–B, p. B86–B91. -1964a, Geologic map of the Fort Ellis quadrangle, Montana: U.S. Geological Survey Miscellaneous Geologic nvestigations Map I-397, scale 1:24,000 —1964b, Geologic map of the Bozeman Pass quadrangle, Montana: U.S. Geological Survey Miscellaneous Geologic Investigations Map I–399, scale 1:24,000. ---1972, Cretaceous and early Tertiary depositional and tectonic history of the Livingston area, southwestern Montana: U.S. Geological Survey Professional paper 526–C, 120 p. Robinson, G.D., 1963, Geology of the Three Forks quadrangle, Montana: U.S. Geological Survey Professional Paper ountain Association of Geologists, p. 271–294.

Schmidt, C.J., and Garihan, J.M., 1983, Laramide tectonic development of the Rocky Mountain foreland of southwestern Montana, in Lowell, J.D., ed., Rocky Mountain foreland basins and uplifts: Denver, Colo., Rocky –1986, Middle Proterozoic and Laramide tectonic activity along the southern margin of the Belt Basin, in Roberts, S.M., ed., Belt Supergroup—A guide to Proterozoic rocks of western Montana and adjacent areas: Montana Bureau of Mines and Geology Special Publication 94, p. 217–235. Schmidt, C.J., and O'Neill, J.M., 1982, Structural evolution of the southwest Montana transverse zone, in Powers, R.B., ed., Geological studies of the Cordilleran thrust belt, volume I: Denver, Colo., Rocky Mountain Association of Schmidt, C.J., O'Neill, J.M., and Brandon, W.C., 1988, Influence of Rocky Mountain foreland uplifts on the development of the frontal fold and thrust belt, southwestern Montana, in Schmidt, C.J., and Perry, W.J., Jr., eds.,

nteraction of the Rocky Mountain foreland and the Cordilleran thrust belt: Geological Society of America Memoir Skipp, Betty, 1977, Geologic map and cross section of the Wallrock quadrangle, Gallatin and Park Counties, Montana J.S. Geological Survey Geologic Quadrangle Map GQ-1402, scale 1:24,000. Skipp, Betty, and Hepp, M.M., 1968, Geologic map of the Hatfield Mountain quadrangle, Gallatin County, Montana: U.S. Geological Survey Geologic Quadrangle Map GQ-729, scale 1:24,000. Skipp, Betty, and McGrew, L.W., 1968, Tertiary structure of the west edge of the Crazy Mountains basin, Montana: Geological Society of America Special Paper 121, p. 637–638 Skipp, Betty, and McGrew, L.W., 1972, The Upper Cretaceous Livingston Group of the western Crazy Mountains Basin, Montana: Montana Geological Society Guidebook, 21st Annual Field Conference, 1972, p. 99–106. --1977, The Maudlow and Sedan Formations of the Upper Cretaceous Livingston Group on the west edge of the Crazy Mountains Basin, Montana: U.S. Geological Survey Bulletin 1422–B, p. B1–B68.

Skipp, Betty, and Peterson, A.D., 1965, Geologic map of the Maudlow quadrangle, southwestern Montana: U.S eological Survey Miscellaneous Geologic Investigations Map I-452, scale 1:24,000. Smith, D.L., 1982, Waulsortian bioherms in the Paine Member of the Lodgepole Limestone (Kinderhookian) of Montana, U.S.A., in Bolton, Keith, Lane, H.R., and Lemone, D.V., eds., Symposium on the paleo-environmental setting and distribution of Waulsortian facies: El Paso, Texas, and Alamagordo, N. Mex., El Paso Geological Society and the University of Texas at El Paso, p. 51-64. Stone, R.A., 1972, Waulsortian type bioherms of Mississippian age, central Bridger Range, Montana: Montana Geological Society Guidebook, 21st Annual Field Conference, 1972, p. 36–55. Thompson, G.R., Fields, R.W., and Alt, David, 1982, Land-based evidence for Tertiary climatic variations—Northern Rockies: Geology, v. 10, p. 413–417. Tysdal, R.G., 1986, Thrust faults and back thrusts in Madison Range of southwestern Montana foreland: American Association of Petroleum Geologists Bulletin, v. 70, p. 360–376.

Winston, Don, 1986a, Stratigraphic correlation and nomenclature of the Middle Proterozoic Belt Supergroup, Montana Idaho and Washington, in Roberts, S.M., ed., Belt Supergroup—A guide to Proterozoic rocks of western Montana and adjacent areas: Montana Bureau of Mines and Geology Special Publication 94, p. 69–84. –1986b, Middle Proterozoic tectonics of the Belt Basin, western Montana and northern Idaho, in Roberts, S.M. ed., Belt Supergroup—A guide to Proterozoic rocks of western Montana and adjacent areas: Montana Bureau of Mines and Geology Special Publication 94, p. 245–257. Wooden, J.L., Mogk, D.W., and Mueller, P.A., 1988, A review of the geochemistry and geochronology of the Archean rocks of the northern part of the Wyoming Province, in Ernst, W.G., ed., Metamorphism and crustal evolution of the Western United States [Rubey Volume VII]: Englewood Cliffs, N.J., Prentice Hall, Inc., p. 383–410. Woodward, L.A., 1982, Tectonic map of the fold and thrust belt and adjacent areas, west-central Montana: Montana Bureau of Mines and Geology Geologic Map 30, scale 1:250,000.



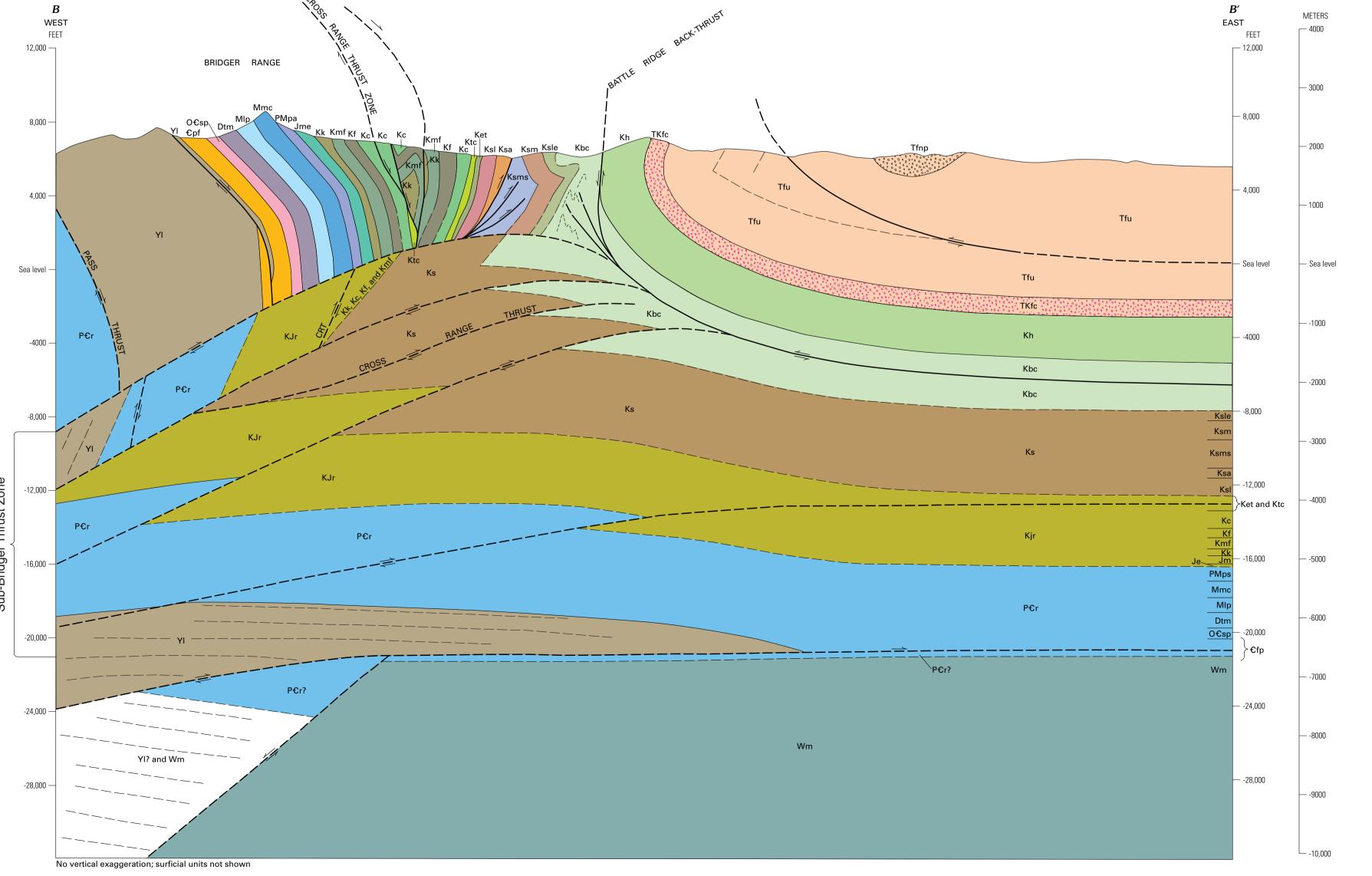
EXPLANATION Structural domains Fault—Dashed where approximately located or concealed Normal or oblique slip—Arrows indicate sense of relative North-central area movement; U, upthrown side; D, downthrown side Cross Range thrust sheet Northern Bridger Range oblique slip Southern Bridger Range

Thrust—Sawteeth on upper plate; U, apparent upthrown side; D, apparent downthrown side; arrows indicate Anticline—Showing crestline. Dashed where approximately located or concealed **Overturned anticline**—Showing crestline and direction of dip of limbs. Dashed where approximately located or

Syncline—Showing troughline. Dashed where approximately located or concealed or concealed

Overturned syncline—Showing troughline and direction of dip of limbs. Dashed where approximately located

No vertical exaggeration; surficial units not show



No vertical exaggeration; surficial units not shown

___=